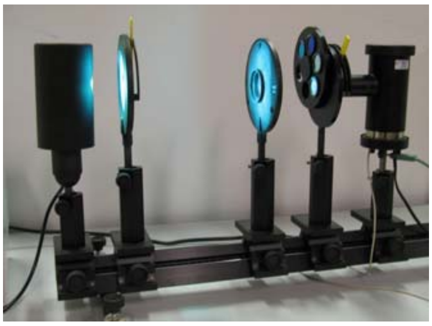
Quick reference guide

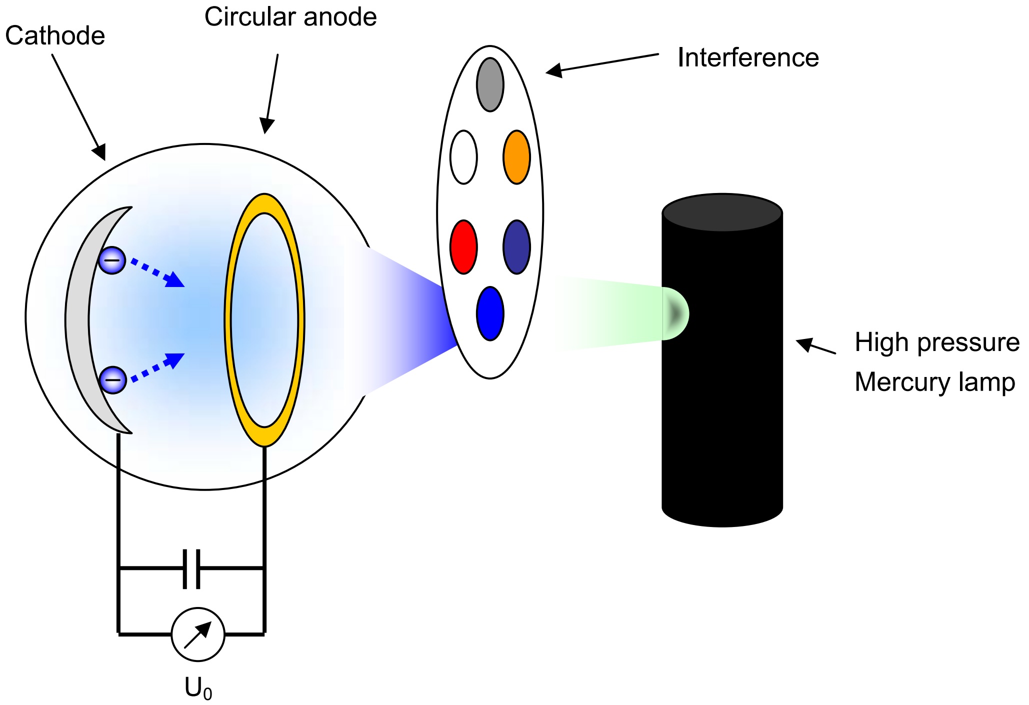
Introduction



The photo cell is used to demonstrate the photoelectric effect. When the photocathode is irradiated with light, electrons are liberated from the photocathode and can be detected at the anode ring as a photoelectric current in a suitable circuit. This device can be used to show that the energy of the light is proportional to the frequency of the radiation and independent of the intensity of the radiation. When the photocathode is irradiated with monochromatic light, it is possible to determine Planck's constant. In addition to confirming Planck's calculations for the radiation of a black body, Einstein's interpretation of these experiments confirmed the quantum nature of light.

Functional principle

- Light is emitted by a high pressure Mercury lamp
- Several lenses focuses the light beam towards the photocell
- Interference filters can be used to select a special wavelength
- Inside the photocell the light causes the emission of electrons at the cathode through photoelectric effect.
- The electrons fly to the circular anode which rise the voltage in the capacitor and the anode. This ends up in an electric field between anode and cathode so that the electrons were slowed down since they are no longer able to reach the anode. The voltage between anode and cathode is a measurement for the energy of the electrons.



Safety precautions

- The high pressure mercury lamp also emits light in the UV range, and can thus damage the eyes. Never look into the direct or reflected beam of light from the high pressure mercury lamp.
- Do not exert mechanical force on the vacuum cell, danger of implosions!

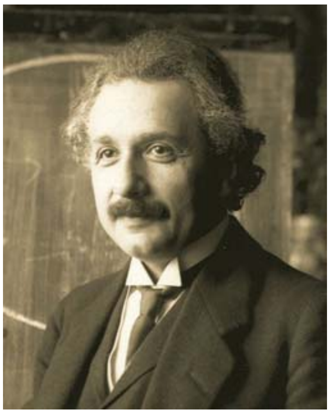
Experimental procedure

1. Switch on the multimeter and set the range switch to 1 V DC.
2. Turn the interference filter for violet light (λ = 405 nm) into the beam path.
3. Discharge the capacitor by holding down the key switch until the multimeter reads zero V.
4. Start the measurement by releasing the key switch; wait about 30 s to 1 minute, until the capacitor has charged to the limit voltage U_0. Write down the measured value for U_0.
5. Turn the interference filter for yellow light (λ = 578 nm) into the beam path and repeat the measurement.
6. What differences between violet (λ=405 nm) and yellow (λ=578 nm) light can be found? How does the limit voltage change if you increase the intensity of the light?

Results:

5. The limit voltage U_0 is much bigger for violet than for yellow light.
6. The intensity of the light does not influence the limit voltage.

With classical wave theory of light we would expect that the emission of electrons does not depend on the wavelength of the light. The photoelectric effect (and the limit voltage U_0) should depend on the intensity, not on the frequency or wavelength of light. How we saw in this experiment, this is not true: the limit voltage is proportional to the wavelength and not to the intensity.



The explanation for this phenomenon was given by Einstein in 1905: he postulated that light consists of a flux of particles, called photons, whose energy E is proportional to the frequency ν:

$E = h \cdot \nu$ (h = $6,62 \cdot 10^{-34}$ Js: Planck's constant)

The irradiated photons may then "hit" an electron in the metal and, if the energy is greater than the ionization energy W of the atom, make the electron exit the atom.

7. Measure the limit voltage U_0 for different wavelengths as described above and fill in the table:

Color	λ (nm)	ν (Hz)	U_0 (V)
Yellow	578	519	
Green	546	549	
Blue	436	688	
Violet	405	741	

8. Plot the measurements in a coordinate system with frequency (ν) on the first axis, and voltage (U_0) on the second, and make a best fit of a straight line trough the points (and/or by linear regression analysis of the measurements) and calculate the slope of the line to determine $^h/_e$ und the ionization energy W of the material of the cathode!

If the photons energy $E = h \cdot \nu$ is greater than the ionization energy W, the rest is found as kinetic energy (E_k) of the electron (the photon “disappears”): $E_{\text{photon}} = W + E_k \Leftrightarrow h\nu = W + E_k$

Since the ionization energy of the atom is a constant, we can calculate Plancks constant *h* by measuring the kinetic energy E_k of the ejecting electrons. We use a photocell with an anode which is used to slow down the electrons which are ejected when we illuminate the cathode layer with monochromatic light. The anode voltage is made by charging a capacitor with the ejecting electrons. The voltage in the capacitor will then rise until the ejecting electrons are no longer able to reach the anode – then we know that the electric potential between the anode and cathode is exactly equal to the kinetic energy. The work done on a charge that falls trough a electric potential *U* is given by $E_U = eU$ (*e* is the charge of the elecrons – the elementary charge). We measure this voltage and wait until it reaches the limit voltage U_0, which then gives us a measure of the kinetic energy of the electrons. Then we can set $E_k = eU_0$ in the above equation:

$$h\nu = W + E_k \Leftrightarrow h\nu = W + eU_0$$

We then are able to express this voltage as a linear function of frequency of the light:

$$h\nu = W + eU_0$$

$$eU_0 = h\nu - W$$

$$U_0 = \frac{h}{e}\nu - \frac{W}{e}$$

This is a linear function with slope $\frac{h}{e}$, so that if we measure the voltage for light with different frequency and find the slope of the best-fit straight line trough these points, we can multiply this by $e = 1.6 \cdot 10^{-19} C$ and get an estimate for Planck’s constant.

<u>Result</u>: The quotient of Planck’s constant (h=6,62*10^{-34} Js) und elementary charge (e=1,6*10^{-19} C) is: $^h/_e$=4,14*10^{-15} $^{Js}/_C$. The ionisation energy of the photocathode is W=1,4274 eV.